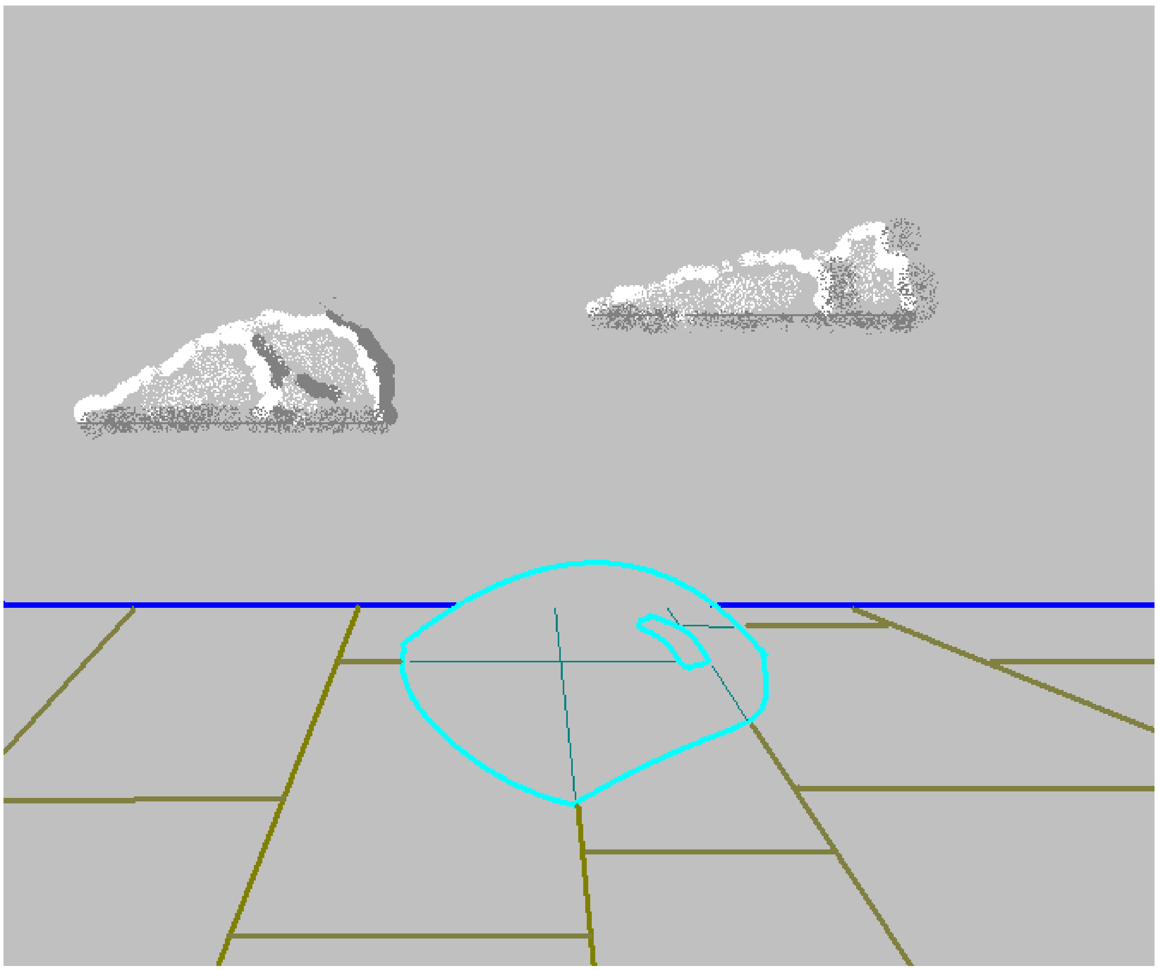
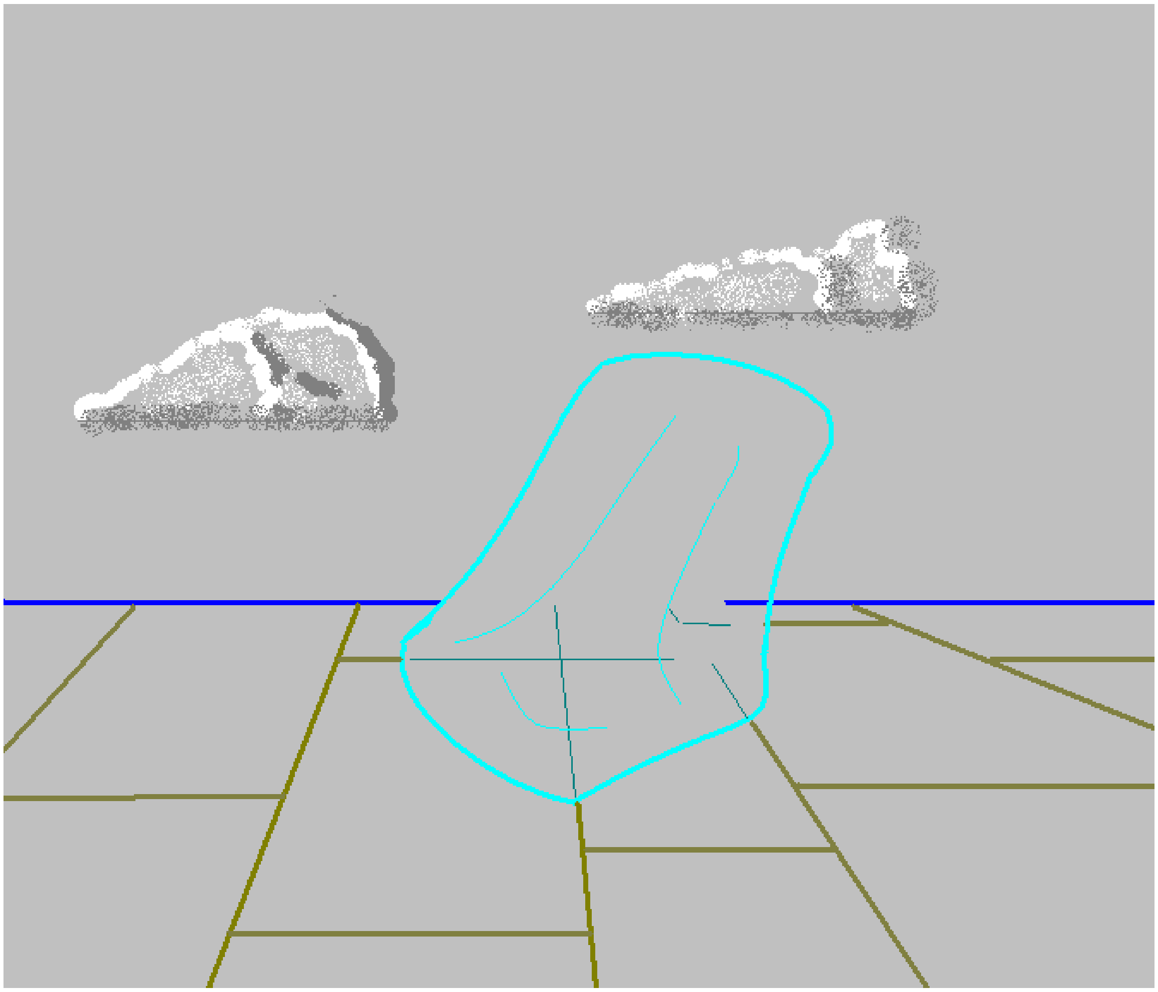
Thermals—Basic Concepts and Models
I: "Warm Bubbles on the Surface"—Free Convection

There are several distinct mechanisms for thermal generation, and we will discuss several of the most important ones here. Bear in mind that each thermal is unique—but at the same time, the majority of thermals on any given day in any given locale usually share many features and characteristics.

The first thermal creation model we'll discuss is the one with which most pilots are familiar. This is the "warm bubble on the surface" model:



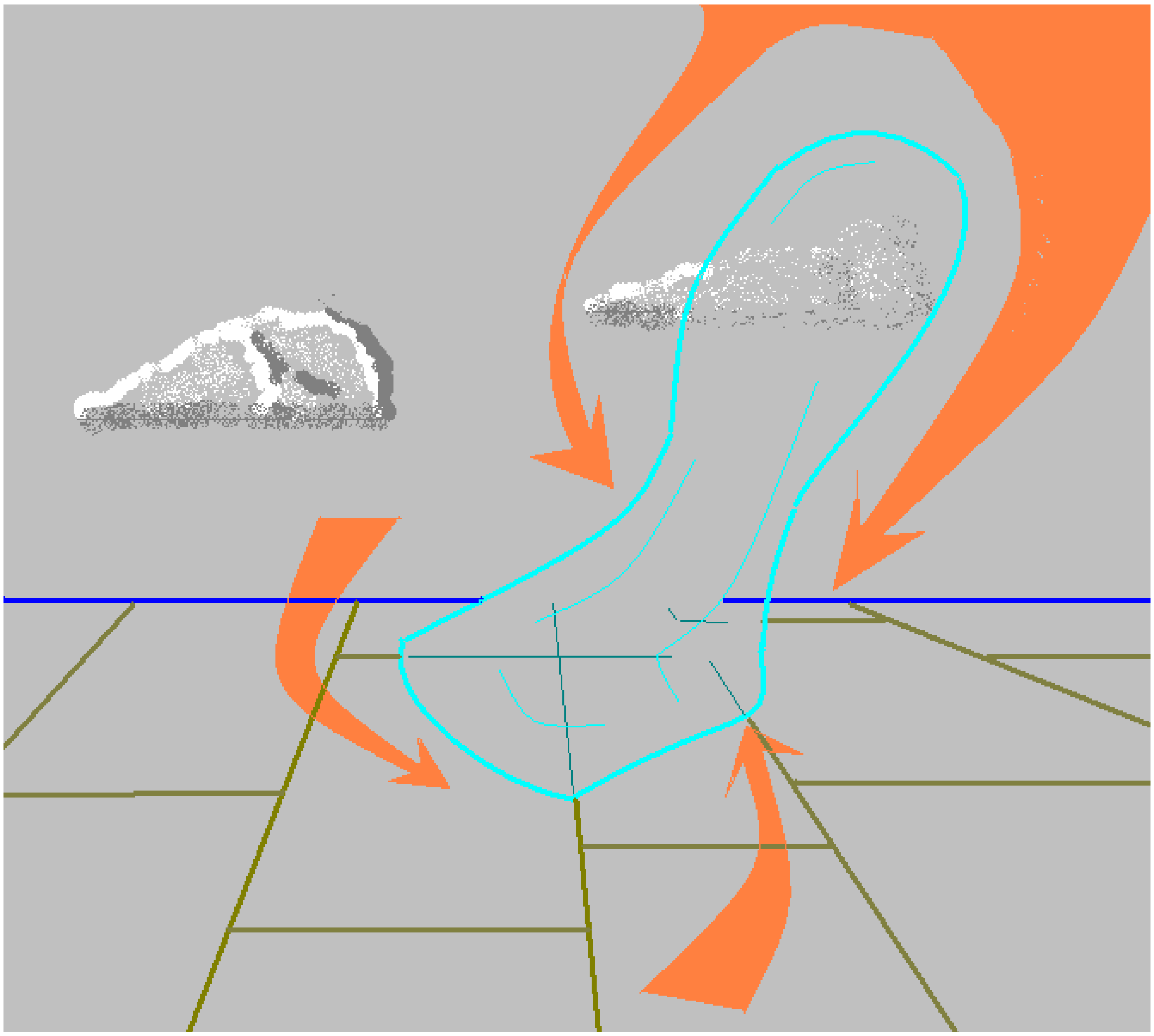
In this model, a bubble of warmed air gradually swells over some favorable spot on the surface. As the temperature difference between the bubble and the surrounding air increases, the bubble forms a long "neck" and behaves something like a hot air balloon being filled:



This phase typically lasts until some sort of “trigger” causes the bubble to break free. In the 1950s, glider pilots in southern California experimented with trigger mechanisms--such as driving automobiles in circles around thermal bubbles on the surface! In Germany, it was common knowledge that glider winch cables often caused thermal bubbles to break free...

At any rate, for whatever reason, the thermal bubble stretches toward the sky and necks down. Cooler air, depicted below in orange, rushes in from above; this will become the well-known sink that usually surrounds a thermal at low altitude.

This cool “sheath” that will eventually squeeze off the neck of the bubble and displace the bubble thus causing it to rise from the surface:



Notice the cool air also rushing in along the surface. This is the reason behind the oft-observed phenomenon of all the windsocks on the airfield pointing at each other... Also, this air, as it converges on the thermal source, largely conserves its angular momentum. This means that when the air arrives at a small radius about the point where the thermal lifted off, it is spinning rapidly. Should there be sufficient dust in this location, the familiar “dust devel” is born:

Just to give you an idea of how universal this phenomenon is, this photo was taken on Mars. (Yes, I know it looks a lot like Nevada.) There is one dust devil in the foreground, and another fainter one in the right background.

Here are the important points to remember about these "warm bubble" thermals:

•Because of the cool air sheath surrounding them, there is sink at their peripheries.

•Because of this, and because of friction with the ambient air, the vertical velocity of the thermal isn't uniform. Instead, the lift is stronger at the core and progressively weaker as you move toward the edges.

•Ambient air becomes "entrained" in the thermal plume, thus making the thermal become physically larger as it rises. Conversely, a thermal is often tiny and narrow at low elevations. Pilots often forget this, and fail to realize that when soaring near ridges at high altitude, the thermals are often quite small because the distance from the surface is short.

•Here's the really important point: the thermal plume keeps lengthening until the warm air bubble (think of it as a reservoir) is exhausted. Once this happens, the thermal becomes a sort of irregular cylinder of finite length, journeying upwards. We must always strive to achieve the best climb rate possible because, once the bottom of that cylinder has reached our altitude, it is "GAME OVER" as far as we're concerned: the train has left the station,and we're not on it!

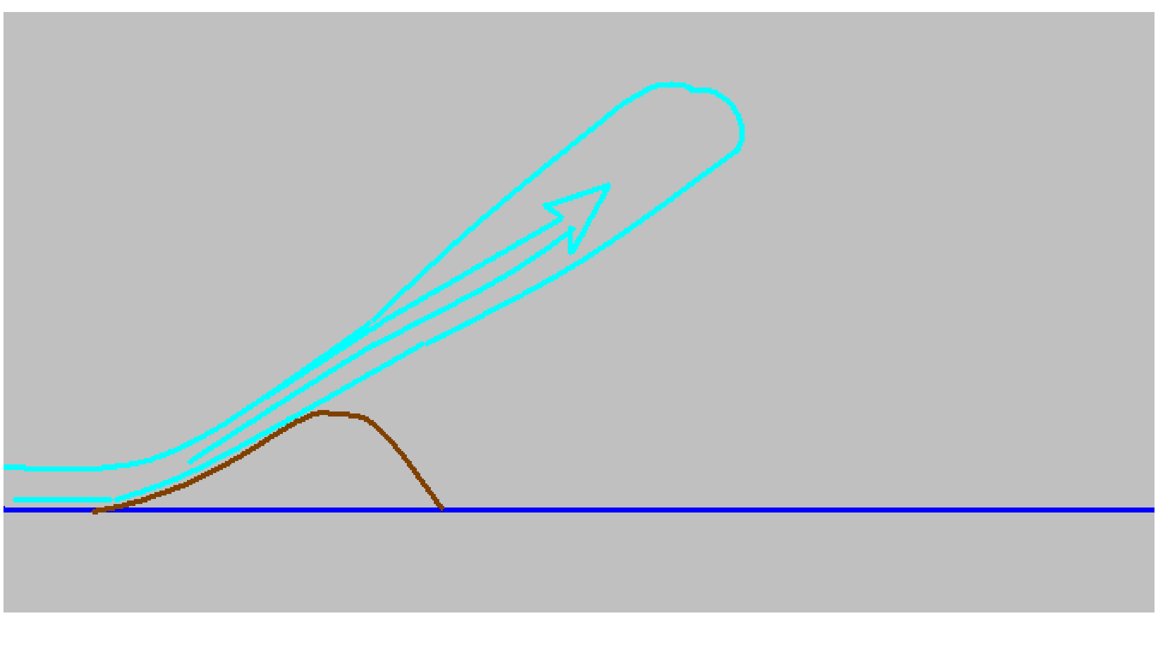
II: Orographically-Induced Thermals

In most meteorological texts, free convection—the "warm bubble" model—is assumed to depend on an ambient lapse rate steeper than the dry adiabatic lapse rate. This is because, in most parts of the world, that's the way it is. However, here in the Great Basin, where extremely strong surface heating combines with high surface elevations and a dry environment to produce very high surface temperatures, it is not strictly true. Rather, we can actually have—and frequently do have—excellent thermal soaring even on days when the lapse rate isn't particularly high, and even when our atmosphere is technically stable.

This is because the surface temperatures are so high (especially considering the elevation) that even when "cooling" adiabatically—the quotation marks are there because while the air temperature is decreasing as the air rises, there is no cooling since 'adiabatic' means 'withut gain or loss of heat'—the air from the surface has to rise quite a distance before it reaches the temperature of the air surrounding it aloft. This is a unique feature of our surface-based thermals here in the Great Basin (and other high desert environments.)

Now let's look at another surface-based thermal generation model, this one depending, however, on atmospheric instability. Glider pilots refer to this model as "thermal ridge" soaring, which is unfortunate because meteorologists use the term "thermal ridge" in a completely different context...but anyway:

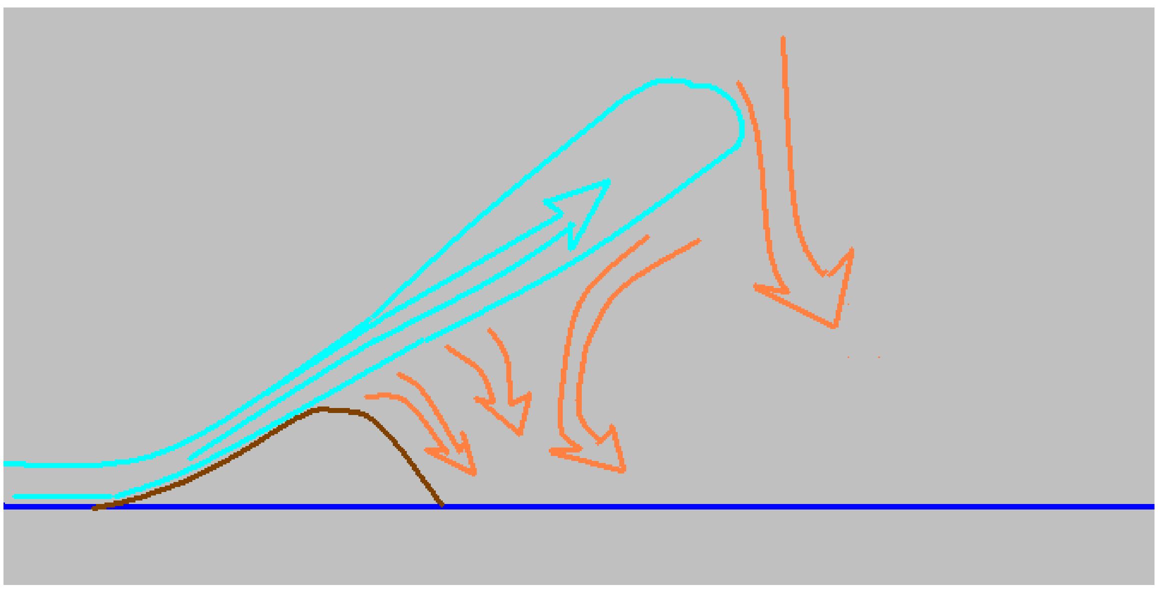
Imagine a day with a good deal of atmospheric instability at and near the surface. Imagine also a gentle breeze flowing across the valley floor. What happens when this air reaches the foot of the nearest hill or mountain?



Here again we have, in a way, a “reservoir” of warm air at the surface. However, this air is not tied to any one spot on the ground, and so isn’t necessarily limited in size as was the “warm bubble” already discussed.

Because the atmosphere is unstable, a parcel of air, once forced upward for whatever reason, continues to rise. (This is consistent with the generalized definition of stability: a stable system, once disturbed, will tend to return to its previous state; by contrast, an unstable system, once disturbed, will tend to magnify the disturbance.) Therefore, the foot of the slope acts as the ‘trigger’ that breaks the parcel loose from the surface.

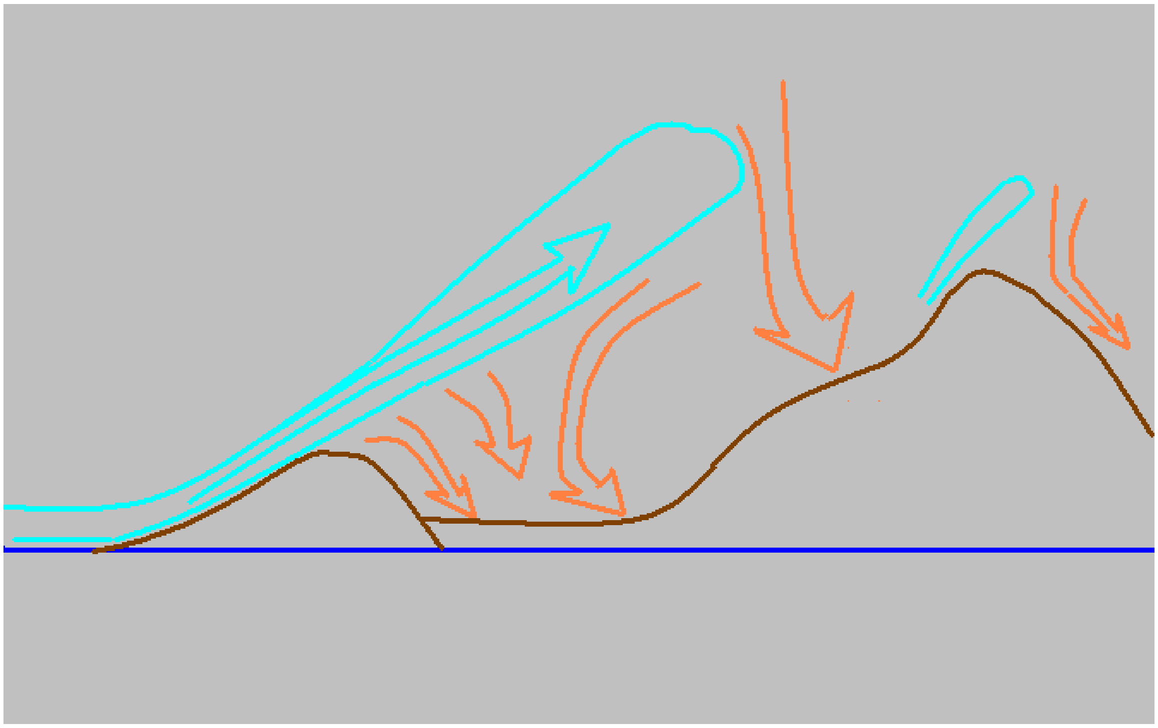
That much is well-known. What is less often appreciated is that instability works BOTH ways: a parcel of air in an unstable atmosphere, once started down, tends to continue descending. So, to complete the sketch above, we should include the descending flows as well:



After all, since the air involved in the thermal must somehow be replaced, there will necessarily be some sink very nearby. With the wind from left to right, it seems reasonable that this sink might lie on the downwind side of the hill—as indeed it does. As the somewhat ragged arrows indicate, this area will also be rather turbulent.

Now, let us suppose that our little hill is just upwind of another, larger ridge. Perhaps it’s even a foothill of the larger peak. How will our little hill affect the flow around the larger one?

Would you like to guess?



Did you guess right? What happened is that the downward flow due to to smaller hill upwind, and its associated thermal, "killed" the lift of the larger ridge downwind. This means that the smaller hill actually provided better lift than the larger hill just downwind of it. Bear in mind that this would NOT have happened in a stable flow; without atmospheric instability to keep the sinking air sinking, there would most likely have been good lift on the larger hill—exactly as the 'ridge-running' crowd might have exected it. Instead, the insignificant little hill offered the best lift in the area!

This is a lot more common than generally realized. This week you will probably get a chance to experience it yourself this week: early in the day, when the surface flow at Air Sailing is from the east, the little 100-ft hill we call "the knoll" will often sustain flight when the much taller Dogskin Mountains won't; in the same way, you'll often find good lift over Winnemucca Ranch Road when the Dogskin peaks aren't working. Likewise, the ridge north of Tule Peak often displays the same behavior; the minor ridge upwind will diminish the lift on the higher ridge downwind.

If you will spend some time trying to visualize the flow across the terrain you see, keeping these ideas in mind, it will pay you great dividends.

So much for thermal ridge effects and thermals caused by topography. Next, we'll look at a thermal generation model that doesn't depend on surface flow at all, but only on the wind.

Here are the important points to remember about orographic thermals:

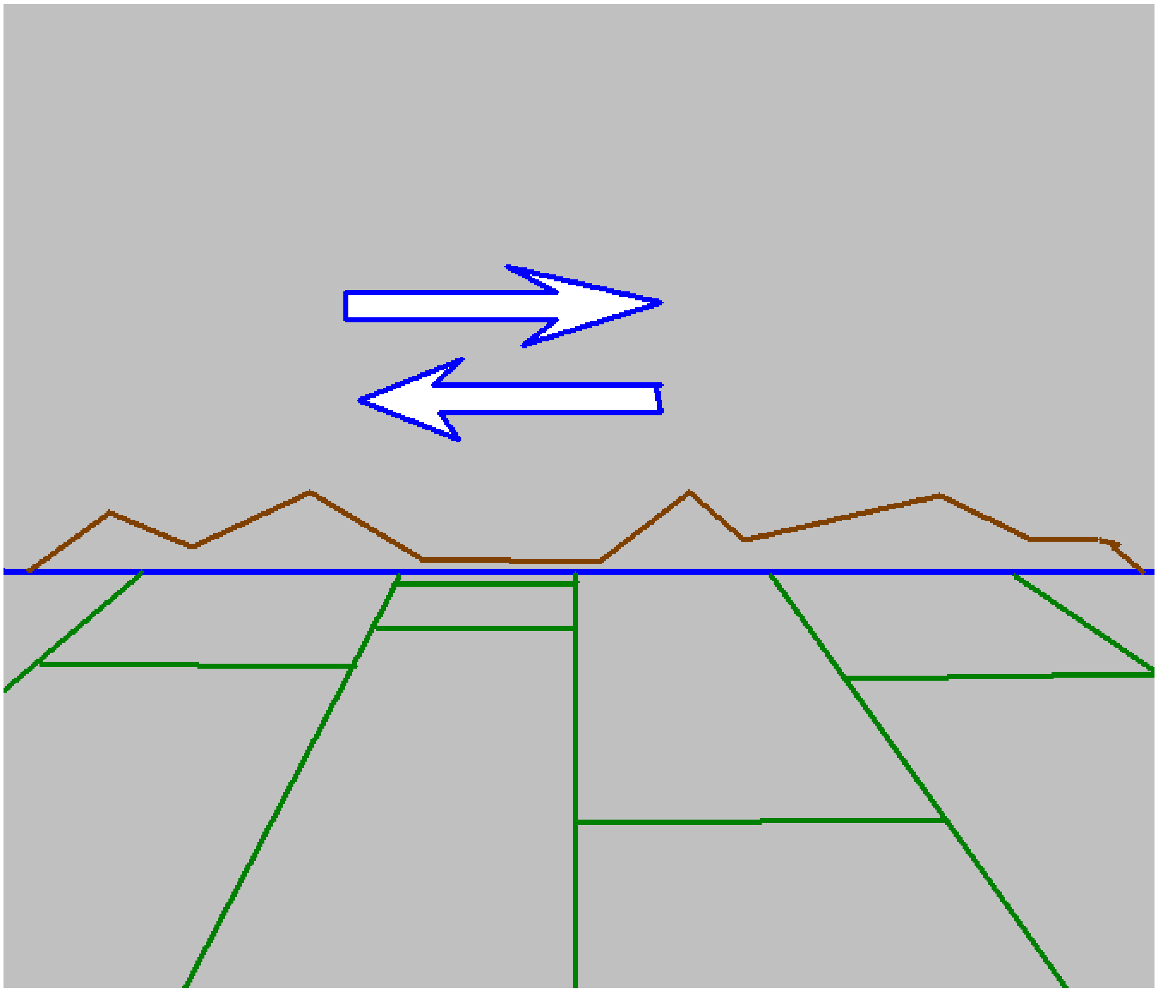
- **They often spring from the bases of ridges, not necessarily from the peaks**
- **They often induce locally-strong sink downwind of them**
- **They often “kill” the lift that might otherwise be produced by ridges downwind of them**
- **Using them often requires a mix of both thermal and ridge soaring techniques**
- **They are often the last convective activity of the day, persisting as long as the mountain peaks are in direct sunlight**

III: Thermals Generated by Wind Shear

As we all know, there is occasionally wind here in the Great Basin. We also know that typically, the winds aloft are stronger than the winds on the surface; they are also commonly from different directions. What all this means is that as we travel from place to place, or as we change altitude, we expect to find that the local winds change, too.

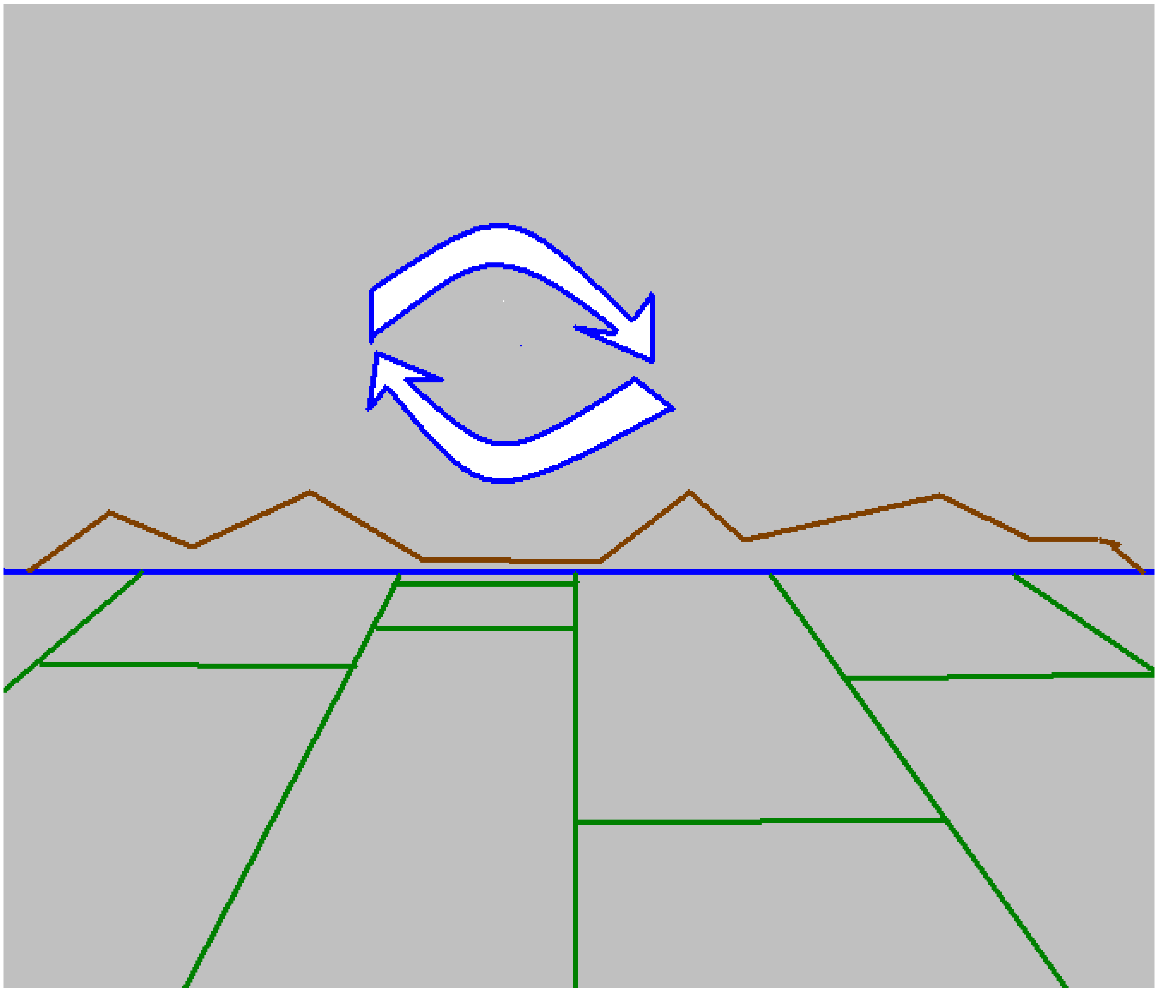
We call any abrupt change in the wind direction or strength within a small distance "wind shear." While there are various types of wind shear, such as the wind gradient with which we must cope on short final, or the dangerous shears induced by thunderstorms, downbursts and other large-scale convection systems, each of them ultimately fits our definition: an abrupt change in wind direction or strength within a short distance.

Air is a gas, and so we don't expect the adjoinng "layers" of it to slip past one another perfectly smoothly. Instead, what happens is that the air tends to get "mixed up" and to form eddies. In flight or on the ground, we experience these eddies as turbulence. But there's a bit more to the story:



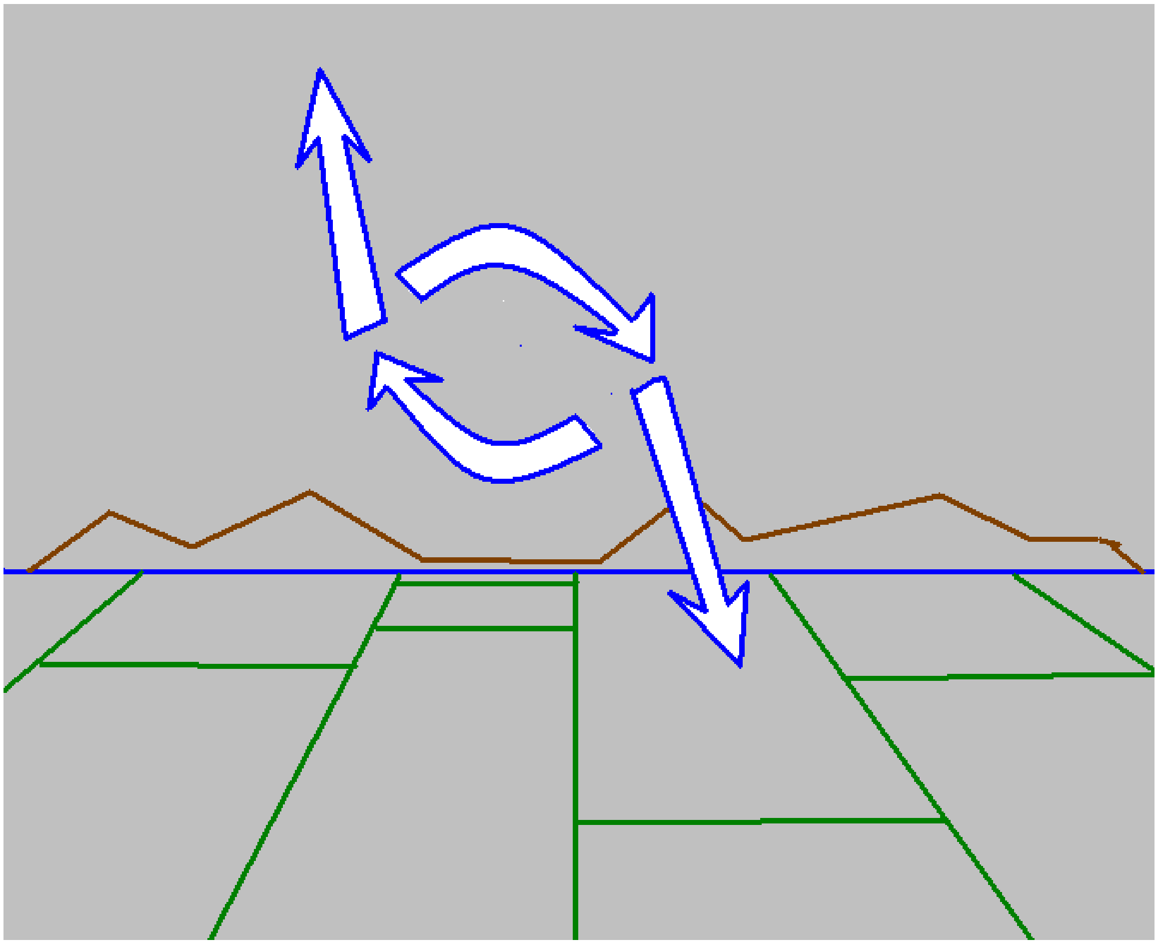
Bear in mind that there is no need for individual parcels of air to actually move in opposite directions; all that is necessary is that they move with different velocities. For example, in the sketch above, the lower parcel might be moving at just 10 kt while the air above is moving at 20 kt in the same direction; there will still be 20 kt of shear between them.

Of course, at the boundary between the two parcels of air, there will be some mixing, and an eddy will form...

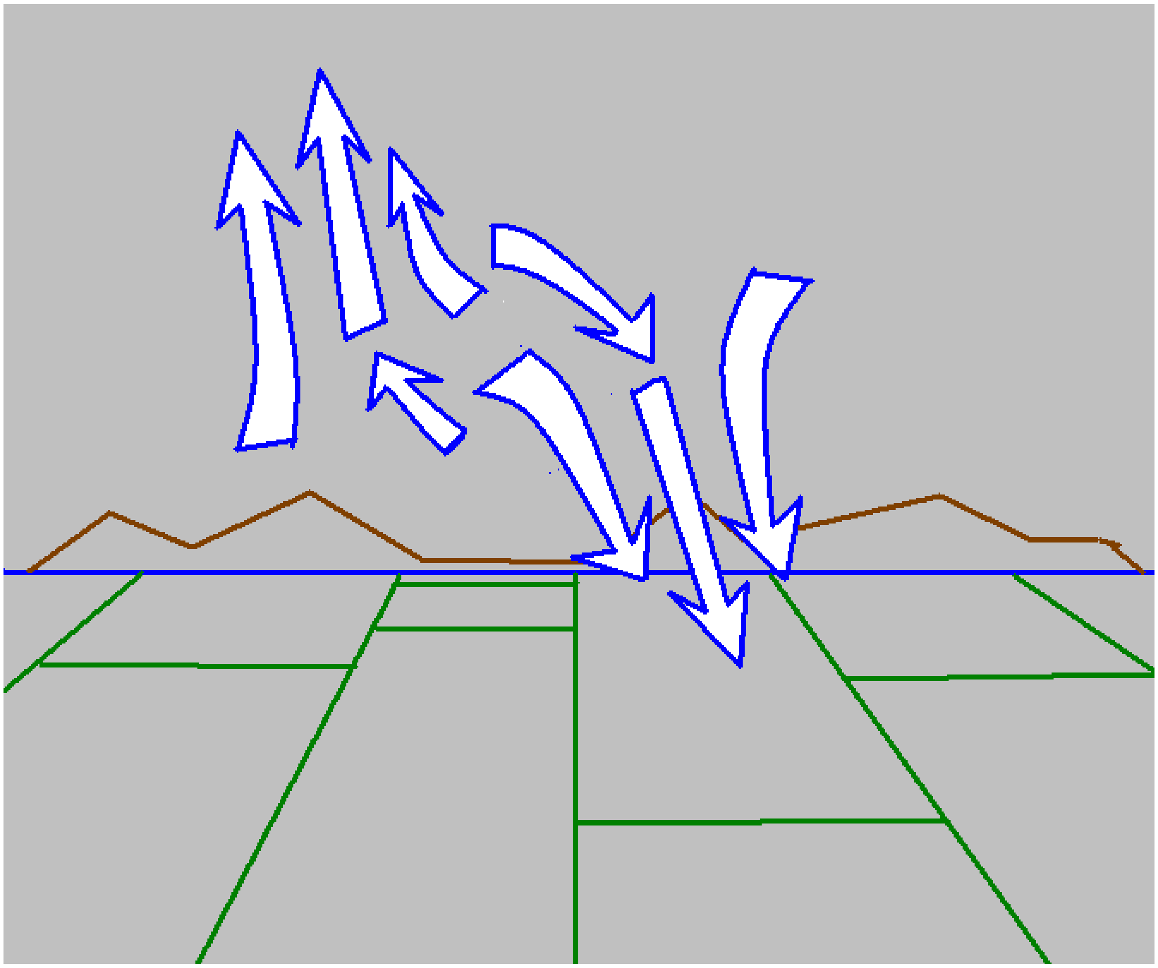


...so that was originally motion in a purely horizontal direction begins to develop some vertical component as well.

If the atmosphere is sufficiently unstable, these vertical currents will become accentuated, as the down-trending parcel finds itself cooler than its surroundings, and the up-trending parcel finds itself warmer than its surroundings.



Notice that not only has a thermal updraft been formed by this process, but also a countervailing downdraft as well. Of course, once each vertical current begins, it entrains additional air from its surroundings...



...this amplification, which turns a small disturbance into a thermal involving literally tons of air, is only possible thanks to the stored energy of an unstable airmass. (This is also why this mechanism only creates strong vertical motion, and not horizontal motion.)

How large an initial disturbance is required? We don't really know. All we can say for certain is that this mechanism is responsible for many of those "no apparent reason for them" thermals that occur, for example, over the valley floors, far from the nearest ridges—and which don't seem to originate at the surface. As every CFIG will tell you, there comes a time each soaring day when it is easy to stay up if one is already at altitude, but difficult or impossible to climb away from a tow. Here in the Great Basin, this windshear-generated thermal model best explains this common observation.

Here are the important points to remember about windshear thermals:

- **They don’t necessarily originate at the surface, and so may not be usable by gliders at low altitudes**

- **They don’t begin until there is sufficient wind—and windshear—to cause them; typically, this means that here in the Great Basin they are produced by the winds caused by “warm bubble” thermal activity**

- **They form more or less randomly, without apparent regard to topography, sun angles, etc**

- **They usually die out late in the afternoon, leaving only the orographic thermals**

IV: Thermals Generated by Insolation

There is a fourth, well-documented thermal generation model that, like the windshear-induced thermal model, doesn't rely on surface conditions. This model requires, however, some source of atmospheric pollutants; incoming solar radiation heats these particles which then heat the air in which they're suspended, thus leading to thermals which don't begin at ground level.

The basic idea is this: air is an almost perfect insulator. Air that does not circulate has a very high insulating value. In fact, down sleeping bags don't work as well as they do because of any special quality of the goose down inside; they work because the goose down traps air—and it is this trapped air that provides the insulating effect.

Sunlight travels through the atmosphere without any appreciable heating effect. This sunlight strikes the ground, heating it, and the ground transfers some of that heat to the air at the surface through conduction. The heated air then rises, thus distributing the heat throughout the troposphere. This, in the big picture, is the function of the thermals we use for soaring flight.

But suppose that, for whatever reason, millions of tiny particles suspended in the air intercept some of the heat from the sun, and warm the air surrounding them? Couldn't this form thermals? Yes—it can, and it does.

In Europe, prior to the 1960s and the general trend toward "green" industry, it was common to seek out and to find thermals above electrical power plants and other large, polluting industrial facilities. In recent decades, however, this has become a much less common practice—because thermals have largely ceased to be generated in this fashion. Here in the United States, glider pilots experimented sometime before 1960 with releasing carbon black from sailplanes in an effort to generate thermals in this manner, albeit with inconclusive results.

What about the Great Basin? To date pollution hasn't been a major enough factor to make power-plant thermals very important to us, but during most summers we do experience one or more periods with very high particulate counts. Where do these particles come from? From fires: range fires, brush fires, forest fires. The trend has been toward ever-increasing risks of fire, perhaps because Baby Boomers are, in increasing numbers, retired to rural developments where accidental fires are much easier to start—and more difficult to suppress.

The resulting "smoke thermals" are, generally speaking, of little use to most sailplanes and pilots. However, Carl Herold and his friends, flying superships out of Ely, Nevada and making use of DoD contacts to open NAS Fallons restricted

airspace, have recently begun utilizing "smoke thermals" to make very long cross-country flights at high altitudes (15,000-24,000 feet msl.) These flights are made using GPS navigation exclusively, as the pilots—due to the smoke--often do not see the ground for hours at a time! For the rest of us, however, smoke thermals will probably remain little more than an historical footnote.

Conclusion

Thermals can be generated through any of several different mechanisms, and undoubtedly there are more of these mechanisms yet to be discovered. Lift is, after all, wherever you find it; certainly no one should 'look a gift thermal in the mouth' just because it doesn't appear to fit some preconceived idea or model. Also, bear in mind that these different mechanisms will often work together to create lift unpredicted by any one model taken separately. Here are a couple of examples:

1) Imagine a hillside directly facing the sun, with no wind. Due to strong localized heating, a warm bubble forms against the side of the ridge. As it begins to stretch out and form a 'neck' it follows the slope of the ground, awaiting some sort of trigger to break free of the surface. That trigger will often be the abrupt change of slope at the top of the ridge, but until that point is reached, the heated air will be confined to a narrow layer right down on the surface. As the thermal bubble flows upward against the face of the hill, it becomes, in effect, an upslope wind; surrounding air will sometimes become entrained in the flow—and so the thermal starts the ridge working as a ridge.

   This shallow layer of upslope flow has a name, by the way: it is "anabatic flow." Much of the soaring done in the Alps is confined to this shallow layer —which is partly why midair collisions are not uncommon there. Anabatic soaring is occasionally practiced here in the Great Basin, notably on the White Mountains and also on the slopes of Mt. Rose near Truckee.

   It is difficult to see or photograph anabatic flow, but fortunately at night, when the peaks cool, the reverse—a downslope breeze kown as "katabatic flow"—sometimes takes place. This flow often lasts until dawn, and in the cooler months fog sometimes forms in this shallow layer. Here's what it looks like:

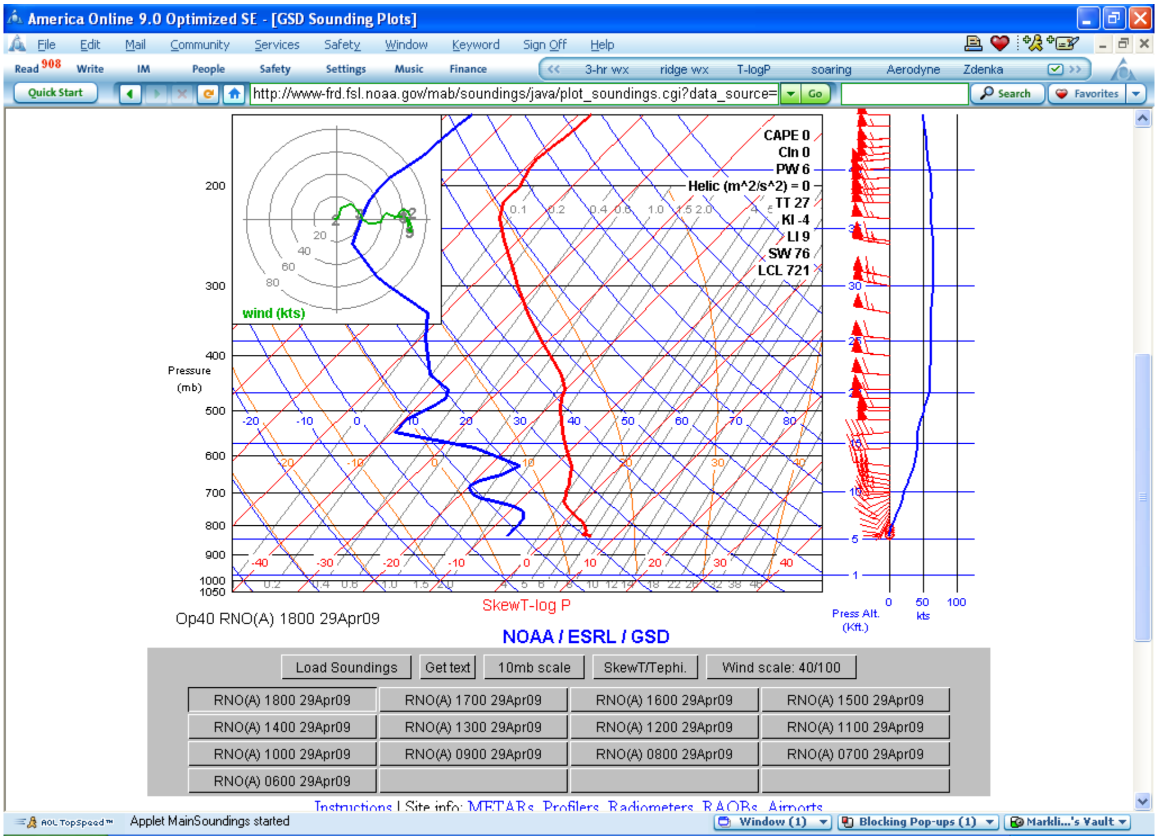
The house in the foreground provides a sense of scale. When the photo was taken, the shallow layer of fog was flowing from right (down a slope that is outside the picture frame) to left, at perhaps 15 kt. The winds were otherwise calm in the area.

As you can see, the layer in motion is extremely shallow; anabatic lift is often confined to within just a wingspan or two from the rocks!

2) Consider a thermal climbing into an altitude at which a substantial windshear exists. The air involved in the thermal, in total many tons of air, has quite a lot of inertia. Therefore, when this air climbs into the shear layer, it won't immediately accelerate to match the "new" wind speed. Instead, it acts as a sort of obstruction to the upper winds. Put another way, it acts as if it were a ridge—thus forcing the oncoming wind to climb up and over it. Should the thermal produce a cloud at this altitude, the leading edge of the thermal will therefore be made visible; in years past it was sometimes possible, while flying in what is now known as Class G airspace, to ridge-soar the upwind face of the cumulus. Just as with an actual ridge, this wasn't normally possible with a small, isolated cumulus, but rather with a large cloud arranged across the upper winds. (Therefore, it was usually necessary to have an abrupt change in wind direction near cloudbase for this to work.)

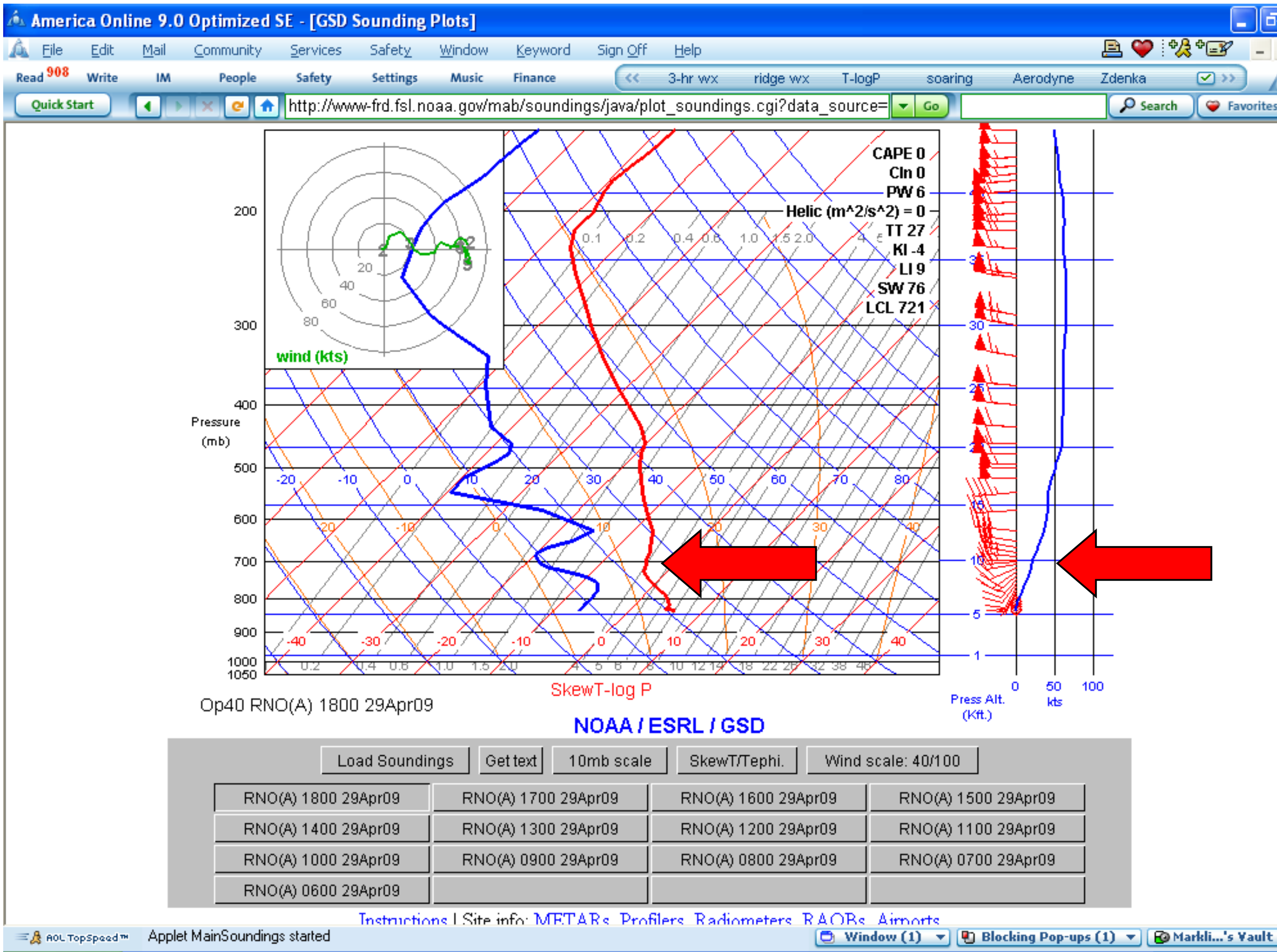
3) Subsidence aloft tends to increase stability below and to inhibit convection; rising air aloft, by contrast, decreases stability and promotes thermal convection. On days with sufficient moisture to roduce cumuli, here in the Great Basin it is common to see the clouds arranged in long rows across the wind (and, therefore, NOT cloud streets) and parallel to the mountain ranges upwind. This is evidence that there is likely to be wave flow aloft; the thermals will flourish beneath the wave peaks and be suppressed beneath the wave troughs. On days such as these, it is often possible to climb to the tops of the thermals, then penetrate upwind into the wave.

   Of course, it is often possible to do this on "blue" days as well; in this case there won't be as many clues to what's going on, but there will still be clues. Take a look at the following logP-skew T sounding, which pertained to a day which was absolutely cloudless the entire day:



This is the 1800Z sounding for Reno on April 29, 2009.

What do you see here?



Notice the temperature inversion between approximately 750 and 650 mb, which corresponds to an altitude range of 8,000 to 12,000 feet msl—about equal to the height of the ridges in this area. Also notice the steep WSW wind gradient at about the same altitude band, with the 700mb wind at 20 kt.

Below this inversion, there was enough instability to ensure good thermal prospects, even with the strong low-level winds.

The winds aloft at the higher altitudes (look at the circular diagram at the upper left corner of the sounding) were uniformly out of the west, reaching a peak of about 70 kt at 30,000 feet.

Does this look like a wave day to you?